REMOTE SENSING APPLICATIONS IN FORESTRY

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REMOTE SENSING APPLICATIONS IN FORESTRY

MULTISTAGE, MULTIBAND AND SEQUENTIAL IMAGERY TO IDENTIFY AND QUANTIFY NON-FOREST VEGETATION RESOURCES

by

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Forest Service, U. S. Department of Agriculture

Final Report 30 September 1972

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California
A Coordination Task Carried Out in Cooperation with
The Forest Service, U. S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PREFACE

On October 1, 1965, a cooperative agreement was signed between the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) authorizing research to be undertaken in remote sensing as related to Agriculture, Forestry and Range Management under funding provided by the Supporting Research and Technology (SR&T) program of NASA, Contract No. R-09-038-002. USDA designated the Forest Service to monitor and provide grants to forestry and range management research workers. All such studies were administered by the Pacific Southwest Forest and Range Experiment Station in Berkeley, California in cooperation with the Forestry Remote Sensing Laboratory of the University of California at Berkeley. Professor Robert N. Colwell of the University of California at Berkeley was designated coordinator of these research studies.

Forest and range research studies were funded either directly with the Forest Service or by Memoranda of Agreement with cooperating universities. The following is a list of research organizations participating in the SR&T program from October 1, 1965, until December 31, 1972.

1. Forest Service, USDA, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

2. Forest Service, USDA, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

3. School of Forestry and Conservation, University of California, Berkeley, California.

4. School of Forestry, University of Minnesota, St. Paul, Minnesota.

5. School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

6. Department of Range Management, Oregon State University, Corvallis, Oregon.

This report summarizes the significant findings of this research and identifies research results which have been applied or are ready for application. In addition, the work carried on for the reporting period October 1, 1971, until December 31, 1972, is described in detail.

A listing of all research reports produced under NASA SR&T Funding for forest and range studies can be found in the Appendix of this report.

ABSTRACT

This is the fifth and final report to assess the merits of multiband photography from aircraft and spacecraft and multispectral scanner imagery for the interpretation and analysis of nonforest (shrubby and herbaceous) native vegetation. Significant findings include:

1. A multiple sampling technique was developed whereby spacecraft photographs supported by aircraft photographs could be used to quantify plant communities. Color infrared spacecraft photographs were used for mapping general plant community systems. These systems almost always represent groupings of individual habitat types, the elemental unit of plant community classification, due to combined effects of photographic scale and ground resolution. Larger scale (1:20,000 - 1:80,000) aircraft photographs were required to determine the areal extent of the individual habitat types. Still larger scale aerial photographs (> 1:2,400) were required for analysis of community components.

2. Large-scale (1:600 - 1:2,400) color infrared aerial photographs were required to identify individual shrub and herbaceous species. Shrubs were correctly identified more consistently than herbaceous species. Sequential photography was necessary to secure the best data unless single photographic mission planning was required.

3. Herbaceous standing crop biomass was successfully estimated by measuring optical density of film images in large-scale color infrared aerial photographs. Shrub species cover, using a measuring magnifier, was estimated at acceptable levels of accuracy as compared to ground measurements from large-scale color infrared aerial photographs.

4. Microdensitometry, to measure film image optical density, was used to discriminate among specific plant communities (habitat type) and individual plant species on color infrared aerial photographs. Small-scale photographs were best suited for communities because the combined effects of scale and ground resolution integrated the community components into a more homogeneous photo image than the data recorded in large-scale photos. Photos to scales necessary for individual species identification were required to discriminate among the species.

5. Recognition processing of multispectral scanner imagery resulted in discrimination of native plant communities provided the communities were quite homogeneous such as willow meadows, sedge/rush/bulrush meadows, bluegrass meadows, or coniferous tree canopy. Special clustering analyses were required for classification of upland steppe communities.

6. A method to estimate overwinter death losses of mule deer was developed using 1:2,000 scale color infrared photos secured of a small area after snowmelt but before severe carcass degradation occurs. Although ratioing was required to associate ground with photo counts, the technique provides a subsampling base from which operational procedures can be developed that will save ground survey time. Mortality information is required for assessing animal/habitat interactions.

7. A technique was developed to estimate population density of northern pocket gophers, a small burrowing rodent. Using a ratio procedure to relate ground counts of soil surface sign caused by the gophers (mounds of soil) to photo counts from 1:600 scale color or color infrared aerial photos, population density estimates from photos were within 3 percent of estimates made by ground survey.

8. The effects of solar radiation, air temperature, and atmospheric water vapor pressure on the effective radiant temperature (ERT) of deer and the relations between deer ERT and the ERT of bare soil, snow, and sagebrush considering the environmental effects with respect to time of day was determined. Thermal scanning for deer in a cold environment should occur between daylight and sunrise to avoid serious discrimination errors between the animals and background material in the scene.

ACKNOWLEDGEMENTS

The research reported herein was performed under the financial assistance of the National Aeronautics and Space Administration, Earth Resources Survey Program in Agriculture/Forestry, Contract No. R-09-038-002. This is the fifth annual and the final report of accomplishments from April 1968, when initial funding was received, until 30 September 1972. Research and administrative direction were provided by the Rocky Mountain Forest and Range Experiment Station. Cooperation from the Forest Remote Sensing Project, R. C. Heller, Project Leader, Pacific Southwest Forest and Range Experiment Station, allowed securing multiband, large-scale aerial photographs and technical assistance.

Special appreciation is extended to the following for assistance in this research program:

1. Rocky Mountain Forest and Range Experiment Station
    a. P. O. Currie - Mountain Ranges Project
    b. O. C. Wallmo and colleagues - Forest Game Habitat Project
    c. M. J. Morris - Range Biometry Project
    d. M. D. Hoover - Water Yield Improvement Project
    e. M. M. Martinelli - Alpine Snow and Avalanches Project
2. Colorado Division of Wildlife - Game Research Section
    a. R. B. Gill - Research Biologist
    b. P. F. Gilbert - Area Supervisor
    c. In addition, the Colorado Division of Wildlife - Game Research Section provided financial support for the research, "Thermal Sensing of Deer in a Cold Environment".

3. U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Section of Wildlife Ecology on Public Lands
    a. V. H. Reid - Research Wildlife Biologist
4. Forestry Remote Sensing Laboratory, University of California
    a. R. N. Colwell, D. M. Carneggie, and G. A. Thorley
5. University of Michigan - Infrared and Optics Laboratory
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MULTISTAGE, MULTIBAND AND SEQUENTIAL IMAGERY TO IDENTIFY AND QUANTIFY NONFOREST VEGETATION RESOURCES

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INTRODUCTION

Inventory and surveillance of native vegetation and its supporting habitat is an increasingly important facet of total land-use planning and management. This is especially true in light of expanding or redistribution of human populations with increasing demands on natural resource outputs. It is imperative that multiple resource management decisions to meet human needs are commensurate with total resource stewardship. Knowledge of the location, kinds and amounts of native vegetation resources, and continuous inventories for detection and assessment of change in the vegetation or abiotic habitat is a fundamental requisite for those decisions.

Current inventory and surveillance techniques for nonforest vegetation (native vegetation other than trees but including exotic species seeded as permanent cover for conservation and rehabilitation needs), are essentially ground based, tedious, and time consuming, and often with considerable error; therefore, costly and not entirely reliable. Due to these factors, research and development programs must define resource inventory and surveillance techniques applicable to synoptic coverage for real time data input, analysis, and recovery. This need formed the basic problem area for the research subsequently discussed.

This is the fifth and final report of research done by the Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, under Contract No. R-09-038-002 of the NASA Supporting Research and Technology (SR&T) program. First funding was received in April 1968 and research was initiated that year toward the following objectives:

1. To determine the aerial photo scale threshold for identification of native, low-stature plant species (species other than trees) considering film-filter combinations, sequential photography, plant size, plant density, and associated vegetation.

2. To develop aerial photo measurement techniques to quantify kinds and amounts of native vegetation in terms of plant community area, foliar cover, and standing crop biomass.

3. To develop multiple sampling techniques for quantitative analysis of aircraft and spacecraft imagery in relation to kind and amount of vegetation by plant communities.

As the research progressed, two additional objectives were phased into the program:

1. To determine the level of ecological integrity at which multispectral scanner imagery could be used for plant community classification and surveillance. (The level of ecological integrity refers to the community category in the hierarchical system of classification in which the habitat type is the elemental unit of the system.)

2. To develop techniques to monitor wild animals in relation to habitat vegetation with thermal and photographic imagery. (This objective

was expediently designed with the Colorado Division of Wildlife, Wildlife Research Section and the USDI, Bureau of Sports Fisheries and Wildlife, Wildlife Ecology Section.)

For the benefit of potential users of the research results subsequently described, brief descriptions of the research locations are included. The succeeding first section of this report provides summaries of results obtained since initiation of the research. Details of experimental procedures are not included; these can be obtained from previous annual reports and referenced publications. The second section provides details of research done during the last reporting period. A listing of all reports and publications emanating from the SR&T funding is included in Appendix A.

THE STUDY AREAS

Four study areas were located in Colorado; one in New Mexico. The Colorado locations were selected to represent a variety of meadows, steppe, steppe-scrub, and scrub plant community systems, some intermixed with coniferous and deciduous forest types.

The Manitou area in central Colorado, NASA Site 242, has been the primary experimental area and is the location of our ERTS-1 and Skylab experiments being conducted in cooperation with the Forest Remote Sensing Project, Pacific Southwest Forest and Range Experiment Station. The area, at an elevation of approximately 2,350 meters above mean sea level, is typical of much of the lower montane life zone along the eastern slope of the southern Rocky Mountains. The vegetation includes primarily open-to-dense stands of ponderosa pine trees (*Pinus ponderosa* Laws) interspersed with natural herbaceous parks and meadows, willow (Salix L.) communities, and seeded grasslands.

The Black Mesa area in west-central Colorado included mountain parks interspersed among mixed forests of Engelmann spruce (Picea engelmannii Parry) and aspen (Populus tremuloides Michx.) at an elevation of approximately 3,000 meters above mean sea level. The Kremmling site in north-central Colorado comprised a scrub plant community system in which big sagebrush (Artemisia tridentata Nutt.), low sagebrush (Artemisia tridentata arbuscula Nutt.), Vasey rabbitbrush (Chrysothamnus vaseyi (A. Gray) Greene), antelope bitterbrush (Purshia tridentata (Pursh) D.C.), broom snakeweed (Gutierrezia sarothrae (Pursh) Britt. and Rusby), and mountain snowberry (Symphoricarpos oreophilus Gray) were the most abundant species. The elevation of this area was approximately 2,450 meters above mean sea level. The McCoy area, also in north-central Colorado, was a pygmy forest community system where two shrubs, true mountain mahogany (Cercocarpus montanus Raf.) and big sagebrush, were the primary species within the pinyon pine (Pinus edulis Engelm.)/Rocky Mountain juniper (Juniperus scopulorum Sarg.) community. The elevation here was approximately 2,250 meters above mean sea level.

The New Mexico area included those nonforest communities included in Apollo 9 frame 3806 exposed on 12 March 1969. It included approximately 10,000 square miles of landscape in the vicinity of Roswell, extending from Fort Sumner on the north to Lake Arthur on the south and the Capitan Mountains on the west to the Mescalero Ridge on the east. Five higher order categories of vegetation occurred in the area: (1) Grama (Bouteloua

Lag.)-galleta (Hilaria H.B.K.) steppe, (2) creosote bush (Larrea Cav.)-tarbush (Flourensia D.C.) scrub, (3) mesquite (Prosopis D.C.)-oak (Quercus L.) scrub, (4) grama-tobosa (Hilaria H.B.K.) steppe scrub, and (5) dwarf forest (Juniperus L.).

SECTION I

SIGNIFICANT FINDINGS

Multiple Sampling for Community Classification and Area

A multiple sampling technique to estimate the area and, to some extent, the structure of specific plant community systems using spacecraft photography has been developed. It required the supporting use of multiscale aircraft photography since scale and ground resolution of the space photos and the complexity of the plant community systems were such that individual habitat types could not be discriminated using only the space photos. This was done with the Apollo 9 color infrared (CIR) photographs of eastern New Mexico in the vicinity of Roswell.

The sampling design defined was basically a subsampling routine in which larger scale photographs were used successively to sample the next smallest scale photographs for certain attributes. Four aerial photo scales were used and involved:

Platform	Film	Scale
Apollo 9	SO-117	1:2.7 $\overline{M}$ enlarged to 1:750 M
Aircraft	CIR-8443	1:80 M
Aircraft	CIR-8443	1:20 M
Aircraft	CIR-8443	1:2.4 M

The space photographs provided the superior synoptic base upon which only high-order community classification, such as forests and generalized steppe and scrub systems and which represent the initial stratification for a resource inventory program, could be differentiated. These classifications, which represented mapping units, almost always consisted of a group or catena of habitat types, each of which required more detail for specific analysis than could be afforded by the space photos alone. Hence, aircraft photographs were required to secure the detail needed for habitat type analysis.

The selection of photo scale for mapping specific native plant communities or habitat types depended not only on the size of the area, as related to ground resolution of the lens/filter system, but greatly on the scene contrasts among habitat types. Photo scales of 1:80,000 were satisfactory for mapping those units with image boundary characteristics markedly different from adjacent units; that is where the ecotone between units was sharp and narrow. Photo scales no smaller than 1:20,000 were required where the transition or ecotone between units was subtle and broad. An example of the former would be the discrimination between predominately herbaceous habitat types versus those with shrubs where the abiotic environmental factors between the two have resulted in extremely different physical site conditions over short distances. An example of the latter would be where the abiotic environmental gradient was gradual such that changes in the structure of the plant communities was also gradual.

The 1:2,400 scale aerial photographs, by subsampling the 1:20,000 scale aerial photographs, provided reliable estimates of the number of individual shrubs or small trees by species in the New Mexico area. However, the individual shrubs were relatively large, mostly taller and wider than 1 meter, and spacing between individual plants was usually more than 1 meter. Also, those types with shrubs were relatively homogeneous, usually no more than three species per type. This photo scale requirement changes as the individual shrubs become smaller, the distance between them becomes less than 1 meter, and the shrub population becomes more heterogeneous. These requirements are subsequently discussed.

Seventy millimeter format aircraft strip photography at the scales mentioned and dot-grids to cover the effective area of each frame were used to estimate the areal extent of habitat types within the mapped units of the space photographs. Individual frames were considered primary sampling units. Secondary, or subsample units, were defined as squares of four dots each, independent of grid density.

Based on analyses of variance for subsampling statistics, it was determined, for the New Mexico area, that the "best" grid system for estimating habitat type area was 36 dots per inch^2 using 50 percent of the subsampling units. "Best" was defined as that grid pattern which yielded an area estimate with the least standard deviation consistent with minimum cost in relation to sampling intensities. Increasing sample size to 64 dots per inch^2 doubled sampling time for an insignificant decrease in standard deviation estimates. The decrease in sample size to 16 dots per inch^2 increased the standard deviation, as compared to the 36 dot per inch^2 grid, to unacceptable proportions. An example of these comparisons is shown in Table 1.

TABLE 1. COMPARISONS OF STANDARD DEVIATIONS USING VARIOUS DOT-GRID DENSITIES IN RELATION TO SAMPLING TIME AND INTENSITY: PHOTO SCALE - 1:20,000

			Community Type					
			I		II		III	
Subsamples Used	Grid Size	Time	Area	$s_{\bar{y}}$	Area	$s_{\bar{y}}$	Area	$s_{\bar{y}}$
Percent	Dots/in.^{2}	Min.	Percent	Acres	Percent	Acres	Percent	Acres
	16	50	35	0.615	31	0.612	34	0.551
60	36	60	36	0.592	36	0.578	28	0.489
	64	120	37	0.410	40	0.435	23	0.334
	16	15	44	0.626	28	0.728	28	0.784
50	36	40	39	0.565	34	0.570	27	0.461
	64	90	38	0.463	33	0.458	29	0.423
	16	15	43	0.904	37	1.470	20	0.713
40	36	25	41	0.756	31	0.689	28	0.635
	64	55	39	0.555	32	0.481	29	0.499

From these data, the optimum sample size for both primary and secondary units can be determined on the basis of a preselected standard error using optimum allocation equations for multistage sampling. For this example, the number of primary units and secondary units, or subsamples per primary unit for three habitat types, were found to be as follows:

Habitat Type	Optimum Primary Units	Optimum Secondary Units
1	3	18
2	6	12
3	6	13

These data were derived using 1:20,000 scale aircraft photography to subsample the space photography for classifying habitat types and determining their areal extent. The 1:80,000 scale photographs were of limited value due to unacceptable interpretation errors for classifying the specific community systems.

The information provides a primary technique whereby quantitative information about native plant communities imaged in spacecraft photographs can be quantified by sampling with aircraft photographs. From this New Mexico data, it is apparent that at least a 2:1 ratio of secondary to primary sampling units would be required to get acceptable (10 percent standard error) estimates of habitat type area using 1:20,000 scale aerial photographs. The 1:2,400 scale photographs provided reliable estimates of numbers (density) of shrubs and small trees. These requirements may not be applicable to other areas with different kinds of vegetation. Presampling must be considered to determine the sampling constraints required. Details about this research are documented (Driscoll 1969b, Driscoll 1970, Poulton, Driscoll, and Shrumpf 1969).

Plant Species Identification

Shrubs

The film type/scale/season combination for identifying individual shrub species with 70 mm aerial photography has been defined. This is an absolute requirement prior to making structural analyses of plant community systems with aerial photographs. The information enhances smapling procedures whereby 70 mm data is used in concert with standard 9 1/2-inch format aerial photography. This research was done at the Kremmling, McCoy, and Black Mesa study areas.

Identification of individual shrubs was significantly better ($P = 0.01$) on large-scale (1:800 - 1:1,500) color infrared aerial photographs than on normal color (Table 2). Eight of 11 species were identified correctly more than 80 percent of the time on color infrared; two were correctly identified 100 percent of the time. Six species were identified more than 80 percent correctly on color photographs, but none were identified 100 percent correctly. Photo scales smaller than 1:2,400 had limited value except for mature individuals of relatively tall species (> 1 m) in dense stands (crown margins touching or nearly so).

Early July photographs provided the most information about all species considered if an investigator was constrained to a single time of data collection. Identification of some species was improved by using earlier (June) or later (August-September) aerial photographs, depending on the phenology of the species. More detailed information about this research has been published (Driscoll 1970, Driscoll and Francis 1970).

TABLE 2. PERCENT CORRECT SHRUB IDENTIFICATION BY SPECIES AND FILM TYPE -- AVERAGE OF FOUR INTERPRETERS

Plant Species	CIR[1]	D-200[2]
Low sagebrush (*Artemisia tridentata arbuscula*)	100	98
Big sagebrush (*A. tridentata*)	90	93
Mountain mahogany (*Cercocarpus montanus*)	100	92
Parry rabbitbrush (*Chrysothamnus parryi*)	60	54
Vasey rabbitbrush (*C. vaseyi*)	56	50
Broom snakeweed (*Gutierrezia sarothrae*)	93	88
One-seed juniper (*Juniperus scopulorum*)	96	94
Pinyon pine (*Pinus edulis*)	92	90
Bitterbrush (*Purshia tridentata*)	80	50
Cinquefoil (*Potentilla fruiticosa*)	83	79
Mountain snowberry (*Symphoricarpos oreophilus*)	65	53
Mean	82	76

[1]Ektachrome Infrared Aero (Type 8443)

[2]Anscochrome D-200 (Type 7230)

Also, a manuscript elaborating on this research has been submitted to Photogrammetric Engineering (Driscoll and Coleman 1973).

Herbaceous Species

Identification of herbaceous plant species was much more time-dependent than identification of shrubs using large-scale 70 mm aerial color and color infrared photographs. Photo scales smaller than 1:750 have proved to be of very limited value except where population dispersion has created clumps of material.

In areas where herbaceous species develop essentially simultaneously, except for some vernal species, photographs obtained at the time of species maturation provided the best success for individual species identification. For example, differentiation in foliage color of broad-leaved species after fruiting usually results in differential image colors such that individual species can be identified nearly 100 percent correctly in 1:600 - 1:750 CIR aerial photographs. Also, species with relatively large showy flowers, such as orange sneezeweed (Helenium hoopseii A. Gray) or arrowleaf balsamroot (Balsamorhiza sagittata (Pursh) Nutt.), were identified accurately in CIR photography at scales up to 1:750.

In areas characterized by two growing seasons -- late spring-early summer and midsummer , such as the Manitou area -- sequential seasonal photography was required. Early season photographs at scales from 1:600 - 1:800 provided, in general, more accurate identification for most herbaceous species than later season photographs (Figure 1). All species considered, there was little difference between color and color infrared except for grasses. Species like Arizona fescue (Festuca arizonica Vasey),

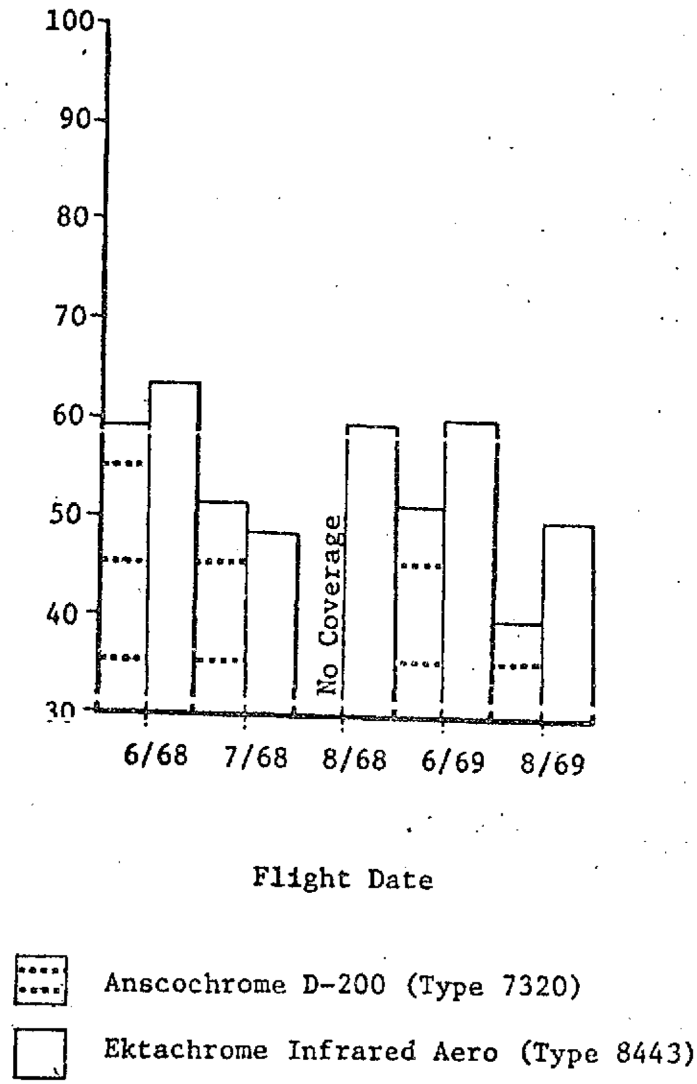

Figure 1. Percent correct identification by film type and flight date. . . all test plant species.

mountain muhly (Muhlenbergia montana (Nutt.) Hitch.), and blue grama (Bouteloua gracilis (H.B.K.) Lag.) were more consistently correctly identified on CIR as compared to color (Table 3). Identification of low-growing broad-leaved forbs was highly variable between film types and among dates of photography. In all cases, bare soil between plants was more accurately identified using the normal-color photographs. In the Manitou area, the color signatures of mat-forming broad-leaved plants, like trailing fleabane (Erigeron flagellaris A. Gray), and bare soil were similar in the CIR photographs.

In general, plants less than 10 cm in diameter could be detected as discrete objects in the largest scale photographs, but the resolution was such that the plants could not be identified. Additional details of this research have been published (Driscoll 1971a, Driscoll and Francis 1970, Driscoll et al 1970).

Measurement of Plant Community Parameters

Standing Crop Biomass

A technique has been developed whereby green standing biomass of a seeded grassland and corresponding harvested dry weight can be estimated using large-scale CIR aerial photographs and image optical density. Image density derived from 1:563 and 1:3,855 scale photographs with a scanning microdensitometer provided valid estimates of either green herbage or harvested dry weight ($r = >0.80$) (Table 4). In all cases, the correlation coefficient was high and significant ($P = 0.01$). The best relationship occurred between image density and harvested dry weight ($r = 0.87$) from the 1:563 photo scale and was expressed by the linear equation:

TABLE 3. PERCENT CORRECT IDENTIFICATION FOR HERBACEOUS PLANT SPECIES AND BARE SOIL SURFACE BY FILM TYPE AND FLIGHT DATE

Item	D-200[1]					EIR[2]				
	6/1/68	7/3/68	8/8/68	6/3/69	8/17/69	6/1/68	7/3/68	8/8/68	6/3/69	8/17/69
	Percent					Percent				
Forbs:										
Pussytoes	70	47	No Coverage	89	59	60	53	86	89	70
Trailing fleabane	73	48		36	0	58	45	61	0	0
Fringed sagebrush	42	16		20	30	34	16	37	27	34
Grasses:										
Arizona fescue	62	59		48	52	74	59	69	69	63
Blue grama	48	73		68	24	80	62	53	73	37
Mountain muhly	54	59		41	36	69	49	40	55	40
Bare soil:	90	72		83	72	35	50	62	63	56

[1]Anscochrome D-200 (Type 7230)

[2]Ektachrome Infrared Aero (Type 8443)

TABLE 4. COEFFICIENTS OF CORRELATION (r) AND DETERMINATION (r^2) FOR IMAGE DENSITY VALUES AND GREEN AND CORRESPONDING HARVESTED DRY WEIGHT; COLOR INFRARED PHOTO SCALES 1:563 AND 1:3855

	Photo Scale	
	1:563	1:3855
Green weight		
r	0.85**	0.81**
r^2	0.72	0.66
Dry weight		
r	0.87**	0.80**
r^2	0.75	0.64

**Highly significant (P = 0.01).

$Y = a + b(X)$ where:

Y = standing crop production (dry weight)

$a = -151.72$

$b = 62.61$

X = image density

Since dry weight determinations may not be operationally feasible to secure, the relationship between green standing crop and image density might be more practical. In this case, an estimate of green standing crop, using the 1:563 photo scale, was expressed by the linear equation:

$Y = a + b(X)$ where:

Y = standing crop production (green)

$a = -281.31$

$b = 115.64$

X = image density

Mean image density of six simulated productivity levels was significantly different among most levels of production represented in both photo scales. These results have been published (Driscoll et al 1972).

Species Foliage Cover

Foliage cover of individual shrub species can be estimated 10 times faster on large-scale (1:800 - 1:1,000) CIR photographs and with comparable accuracy as compared to ground measurements using a line-transect technique. The correlation coefficients between ground and photo measurements of one species, big sagebrush, were highly significant ($P = 0.01$) and greater than 0.86 using a simple measuring magnifier (Figure 2). Accuracy of measurement depends on the interpreter's success in identifying the individual

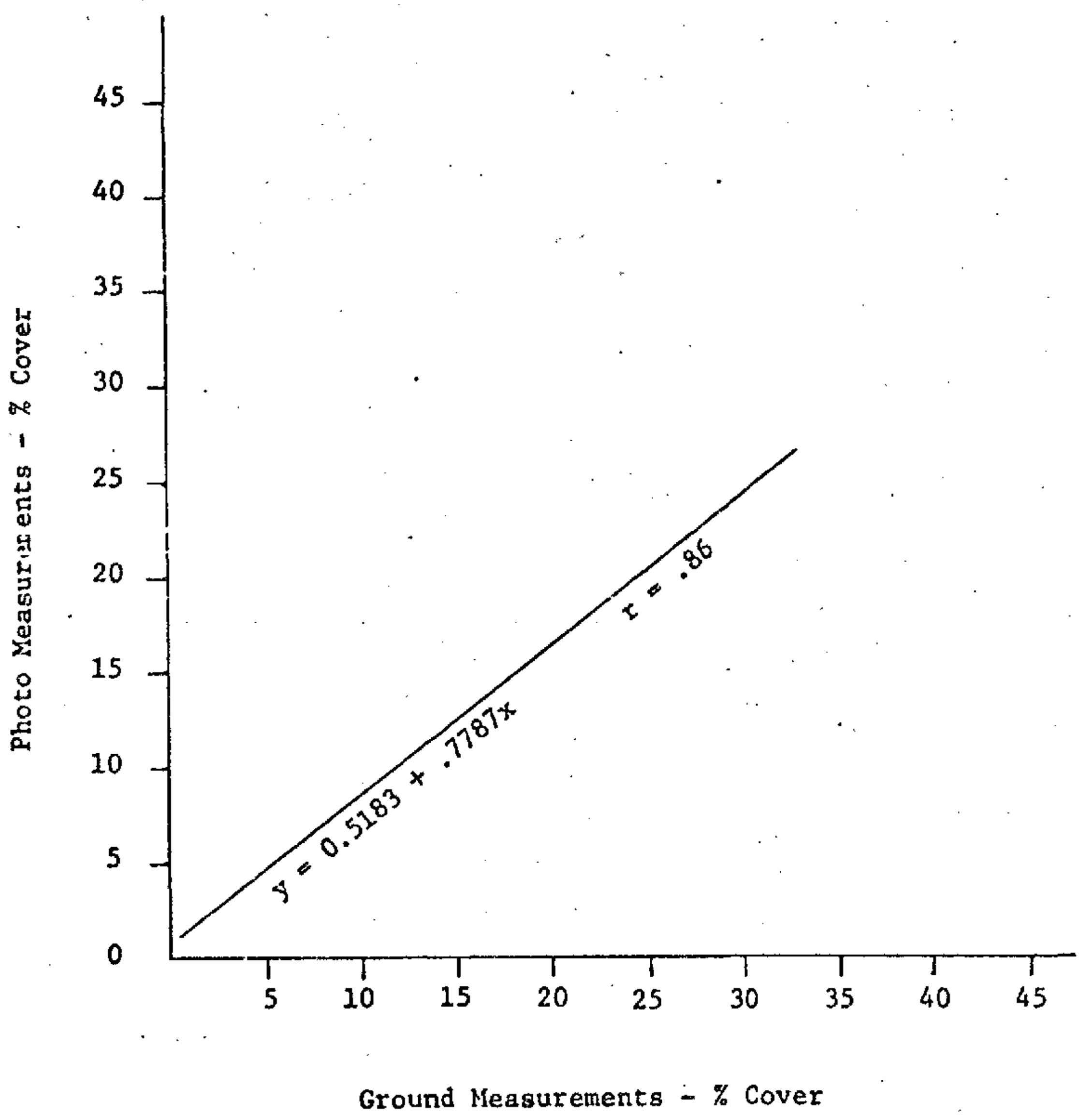

Figure 2. Comparison of ground to photo measurements of percent cover of big sagebrush: measuring magnifier.

species. These data have been published (Driscoll 1970).

Microdensitometry for Species and Community I.D.

The optical density of plant species and community images in aerial CIR transparencies, estimated by a scanning microdensitometer, can be used for semi-automated interpretation of these resource elements. Small-scale photos seemed best suited for discriminating among high-order plant communities such as coniferous forests versus steppe or scrub systems. For example, the mean density (3.7) of ponderosa pine forest at the Manitou area was discretely less than for native steppe (3.04) or seeded grassland (3.25) using 1:139 M photography. In this case, the differences between the two herbaceous communities were also discriminable. Also, image density differences between spruce-fir and ponderosa pine forest systems were discrete.

The image density of selected individual species obtained from 1:1,100 scale CIR transparencies showed discrete differences among some of the species (Figure 3), although the range in density values shows considerable overlap (Table 5). Of prime importance, however, was the fact that the image density and density range of bare soil were significantly less than those of live vegetation for the area where this research was conducted. This procedure identifies a semi-automatic photo measurement technique to monitor change in total plant cover relative to increases or decreases in bare soil.

Some results of this work have been published (Driscoll et al 1970, Driscoll 1971b). Results of all our research done with microdensitometry have been summarized in a manuscript to be submitted to the Journal of

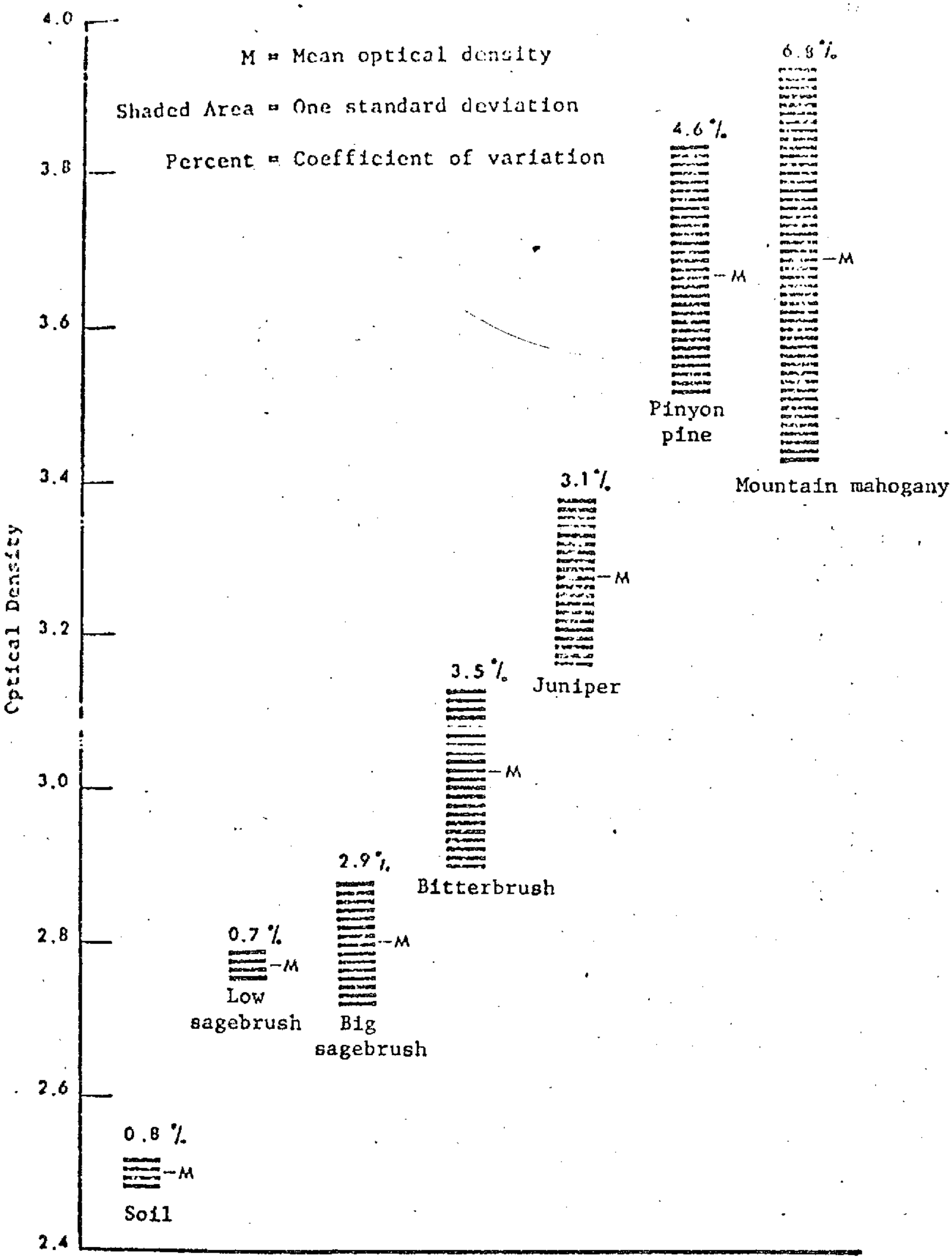

Figure 3. Optical film density through a green filter (Wratten 93) of two trees, four shrub species, and soil. McCoy, Colorado, 6 August 1968, scale 1:1,100, color infrared -- 8443.

TABLE 5. MEANS AND RANGES OF TRANSPARENCY DENSITY VALUES OF COLOR INFRARED IMAGES OF 5 SHRUBS AND BARE SOIL SCALE 1:1,100, PHOTO MISSION 3 AUGUST 1968

	Film density values	
Species or object	Mean	Range
Cercocarpus montanus	3.676	3.15 - 4.42
Pinus edulis	3.655	3.26 - 4.12
Juniperus scopulorum	3.266	3.04 - 3.56
Purshia tridentata	3.169	2.97 - 3.53
Artemisia tridentata	2.805	2.56 - 3.00
Artemisia longiloba	2.768	2.62 - 2.72
Bare soil	2.497	2.44 - 2.58

Range Management (Reppert et al. 1973).

Multispectral Scanner Imagery for Plant Community Classification

Multispectral scanner imagery coupled with automatic data processing may be an integral part of future land management decisions for classifying and monitoring changes in nonagricultural vegetation. Although it has been demonstrated that the technique can be used for high-order vegetation categories, i.e., forests and bogs, it has not been known with certainty the specific level of integrity in the ecological hierarchy of plant community classification at which the method is applicable.

The results of recognition processing of 10-channel multispectral scanner data identified six as providing the best information for computerized classification of 11 plant communities ecologically identified by ground research. The communities were established on the basis of current aspect and relative similarity of composition of plant species components. Two nonvegetation categories, asphalt roads and bare soil, were also included. The six best channels chosen on an ordered selection scheme were:

Channel No.	10% Peak Power Bandpass (μm)
10	0.604 - 0.700
12	0.725 - 0.920
5	0.478 - 0.508
9	0.566 - 0.638
7	0.514 - 0.558
6	0.492 - 0.536

The recognition processing provided acceptable discrimination of high-order categories which were ponderosa pine forest and all upland steppe communities. Specific communities ecologically classified to the habitat type level that were adequately recognized were willow meadows, native bluegrass meadows, and sedge/rush/bulrush meadows.

Apparent problems in computerized classification of steppe community systems occurred whenever the proportion of bare soil and plant litter on the ground exceeded the proportion of live vegetation foliar cover. A clustering technique, which used the probability of misclassification to determine spectral similarity of representative training areas for the computerized recognition processing, improved classification of the steppe systems. These results have been summarized (Driscoll 1971b) and will be published in the 8th International Symposium on Remote Sensing of Environment Proceedings (Driscoll and Spencer 1972). This research was done at the Manitou area.

Wild Animal-Habitat Relations

Simply knowing and understanding the vegetation of an area is not sufficient for understanding the dynamics of the ecosystem. Animal/habitat/vegetation interactions are important considerations,and animal mortality, as a part of total population dynamics, is a needed function to assess animal/vegetation relations.

Large-scale (1:2,000) CIR aerial photographs may be applied to assess overwinter mule deer mortality on winter ranges similar to those around the Kremmling area. On the average, five interpreters identified 68 percent of known imaged carcasses. Omission errors were relatively high, 32 percent, but this was due primarily to late season (July) photography. At that time, carcass decomposition and disturbance by scavengers made detection, even by ground search, difficult except by very close observation.

This research was sponsored partly by the Game Research Section, Colorado Division of Wildlife to coordinate with our SR&T research on inventory and surveillance of native vegetation. Preliminary results have been summarized (Driscoll and Gill 1972), and upon completion of analysis of data obtained in May 1972, a manuscript will be prepared for publication in a technical journal.

SECTION II

CURRENT YEAR ACTIVITIES

Primary effort during the current year has been devoted to completing two studies dealing with habitat/wild animal relations. The habitat/animal remote sensing research, in addition to being part of the SR&T program, was coordinated with and supported partly by ongoing research of the USDI, Bureau of Sports Fisheries and Wildlife, Wildlife Ecology Section and the Game Research Section of the Colorado Division of Wildlife.

Aerial Photos and Pocket Gopher Populations

Western pocket gophers (*Thomomys* spp.) are small indigenous rodents inhabiting most areas in the western United States. The northern pocket gopher (*Thomomys talpoides*) is common to the high mountain forests, parks, and meadows in Colorado and adjacent areas. This small rodent, during high population cycles, frequently causes severe disturbance to the landscape due to its vegetation consumption and soil disturbance activities. For example, average populations (15 per acre) consume approximately 1,100 pounds of fresh herbage per year in areas like the Black Mesa site. During expected population increases, these rodents, which colonize, would consume a significant amount of total standing crop biomass. In addition, burrowing and soil surface mounding activities create possible deleterious effects on the ecosystem by increasing the potential of accelerated soil erosion. However, the rodent is a part of the cybernetics of the ecosystem and contributes an important function to the integrity of the system. Therefore, knowledge about the population dynamics of the animal and its effects on the habitat are a part of understanding ecosystem structure and function.

The degree of earth mounding of these rodents in the late summer is directly related to population density and, hence, periodic changes in this activity relate to population fluctuations and predictions on effects on the ecosystem. The earth mounds (Figure 4) are conical shaped mounds of soil deposited on the soil surface as a result of subsurface burrow-building. New mounds have a fluffy appearance and are darker colored than the surrounding soil surface. Old mounds that have been exposed to the elements are crusty and assume the color of the undisturbed soil surface. These characteristics were exploited for preliminary interpretation of large-scale (1:600 - 1:2,400) CIR aerial photographs for discrimination between old and new mounding activity (Driscoll 1971a). The hypothesis of this experiment was that pocket gopher density (numbers) could be estimated using large-scale aerial color and/or color infrared aerial photographs.

Procedures

Three pairs of approximately 1-acre (0.41-hectare) plots were located in park areas at Black Mesa with known populations of northern pocket

Figure 4. Pocket gopher earth mound. New mounds have a fluffy appearance and are darker in color than the soil surface or mounds that have been exposed to the elements for a few days. These characteristics were exploited for interpreting current mounding activity in large-scale (1:600) CIR aerial photographs.

gophers. Within each plot, twenty 0.01-acre (0.0041-hectare) subplots were located by random selection such that five occurred in each quarter of the large plots.

Within the subplots of one large plot of each pair, all gopher mounds were obliterated 48 hours prior to a planned photo mission. Such signs in the other plot of each pair were left untouched. This was done to test the additional hypothesis that "old" mounds could be discriminated from "new" mounds using the resultant aerial photographs. Counts of new gopher mounds on all plots were made during the photo mission. Sampling requirements and the mound counting-time interval were established by research personnel of the Bureau of Sports Fisheries and Wildlife for monitoring gopher populations by ground survey.

The photo mission was flown August 31, 1971, between 1030 and 1120 hours, Mountain Standard time. Two film types, Aerochrome infrared (Type 2443) and Ektachrome Aero (Type 8442) were flown for two photo scales, 1:600 and 1:1,200. The photography was obtained using the Forest Service Aero Commander 500B with a dual mounted Maurer KB8-A camera system.

Results and Conclusions

Interpretation of 1:600 scale color or color infrared aerial photographs to count northern pocket gopher mounds for establishing population densities of the rodent were 97 percent as accurate as ground survey only (Table 6). There was no significant difference between film types. However, interpreters favored the CIR since it was relatively easier to positively discriminate between live vegetation and non-vegetated areas with

TABLE 6. COMPARISON OF POCKET GOPHER POPULATION PER ACRE (0.41 HECTARE) ESTIMATED BY GROUND TRUTH SIGN COUNTS AND PHOTO INTERPRETATION SIGN COUNTS USING 1:600 SCALE COLOR OR COLOR INFRARED PHOTOS*

		Normalized P.I. Estimates by Interpreter		
Plot	Actual Population	I	II	III
A	41	38	40	36
B	34	44	36	40
C	28	25	30	35
D	22	35	37	28
E	40	26	29	32
F	40	31	26	25
Mean	34	33	33	33

*Data normalized over all subplots for each interpreter.

this film type. Earth mounds were generally not discernible with acceptable accuracy in the 1:1,200 scale photos except where they had been marked on the ground for positive photo identification.

Data on interpreted mound counts from the aerial photos were normalized to actual ground counts by ratioing: $R = \frac{\text{Ground counts}}{\text{Aerial photo counts}}$. This ratio was determined for each subplot and also on a large plot basis. The resultant data were then applied to the equation:

$$\hat{Y} = 0.6582 \sqrt{RM} \log (RM+1) \text{ where:}$$

$\hat{Y}$ = estimated population density

R = normalized mound count

M = photo identified mound counts per acre

to provide an estimate of animal density per area.

The best population estimates through photo counts, as compared to actual ground counts, were obtained when the data for individual interpreters were used independently rather than combined from all interpreters. Using combined data from all interpreters to establish a common denominator, two interpreters overestimated the apparent population density by 6 percent, a third interpreter underestimated population density by 15 percent. Independently, each of three interpreters provided population density estimates that were only 3 percent less than was obtained by ground-based estimates.

Population estimates of northern pocket gophers can be obtained using the technique defined, and this information can be used to monitor change in relation to influences on the habitat. However, subsampling routines must be a part of an operational procedure since the relationship between ground and photo-interpreted data must be established.

Results of this research are being prepared as a Master of Science thesis (Watson 1973) by Thomas C. Watson, who is a Range Technician with the Rocky Mountain Forest and Range Experiment Station, and also a Graduate Student in the Range Science Department at Colorado State University under the direction of the Principal Investigator, Richard S. Driscoll. A technical journal or Experiment Station paper reporting the results is planned.

Thermal Sensing of Deer in a Cold Environment

Mule deer and other large herbivorous mammals which inhabit mountainous areas at mid-to-high latitudes in the western United States are forced to migrate seasonally to gain access to food supplies. This occurs during the fall of the year when snow covers the vegetation at higher elevations and the animals must move to areas of less snow depth to survive. Generally, these "winter ranges" are smaller in area than the "summer ranges" and, hence, are a primary controlling mechanism governing size, structure, and general health of the animal population, as well as the condition of the habitat. Thus, it is important not only to know how much and where the accessible vegetation for animal sustenance occurs on the winter ranges, but also the size of the animal population dependent on it. The resource manager needs this information to make necessary adjustments required to establish healthy habitat/animal balance and to avoid serious animal losses due to starvation or epizootic outbreaks. Other kinds of animal populations exhibit similar interactions with their habitat, and it is not infrequent that certain segments of the habitat are the controlling mechanism for healthy populations.

To determine populations and assess population dynamics in relation to habitat has required tedious ground search techniques, although aerial photos and direct visual observation from the air have been used for wild animal counts. However, these techniques require daylight, a time during which the animals are frequently hidden from view due to their nocturnal habits. Therefore, thermal scanning, which is not light dependent, provides a potentially useful technique to assess habitat/animal interactions.

That thermal sensors can detect deer and other mammals is known. However, it is not known what the environmental constraints are that will permit the obtaining of maximum information about the animals in relation to their habitat. This need formed the basis for research having the following objectives: (1) To determine the effects of various environmental factors on radiant temperatures of mule deer in a cold environment, and (2) to determine when, in terms of the environmental factors studied, detection by a thermal scanner would be most likely.

Procedures

Four tame mule deer were placed in an open-air exclosure, 30.5 x 61 meters in size, located on a 17 percent southwest slope. This site, within the Kremmling area, is environmentally typical of most winter mule deer ranges in the western United States. The exclosure had been built by the Colorado Division of Wildlife for research on other aspects of deer/habitat relationships.

Data about the deer and certain environmental factors were secured during the cold season, January-March. This season was chosen for two reasons: (1) previous attempts at thermal scanning for deer detection emphasized the desirability of a cold background, (2) for practical applications, detection missions would likely be planned during the winter season when the animals are concentrated on limited areas free of tree overstory.

Effective radiant temperatures (ERT) were measured with a Barnes PRT-5 precision infrared radiometer during selected sample periods throughout the 24-hour day. This included information about deer, snow, sagebrush (the plant species most frequently protruding above snow), bare soil, and solid rocks. The same sagebrush and rock surfaces were used during all data collection periods. Snow and bare soil sample surfaces varied somewhat due to the variation in snow cover during the data collection periods. Deer measurements were obtained whenever the animals were within 40 feet of the observer, a constraint placed by the radiometer with its 2^{o} field-of-view. To have positive control over the target surface viewed, a 4-power telescopic sight was mounted on the radiometer head. All ERT measurements were made from a specially constructed platform extending into the exclosure (Figure 5).

Environmental factors measured included air temperature, windspeed, atmospheric water vapor pressure, and solar radiation. Air temperatures were recorded continuously with a United Electronic Controls Company thermograph and, at the start and end of each sampling period, by a mercury thermometer. Windspeed was measured at two points in the enclosure by Casella cup anemometers. Atmospheric water vapor pressure was measured by a sling psychrometer. Solar radiation was measured by a Kahl Scientific star pyranometer.

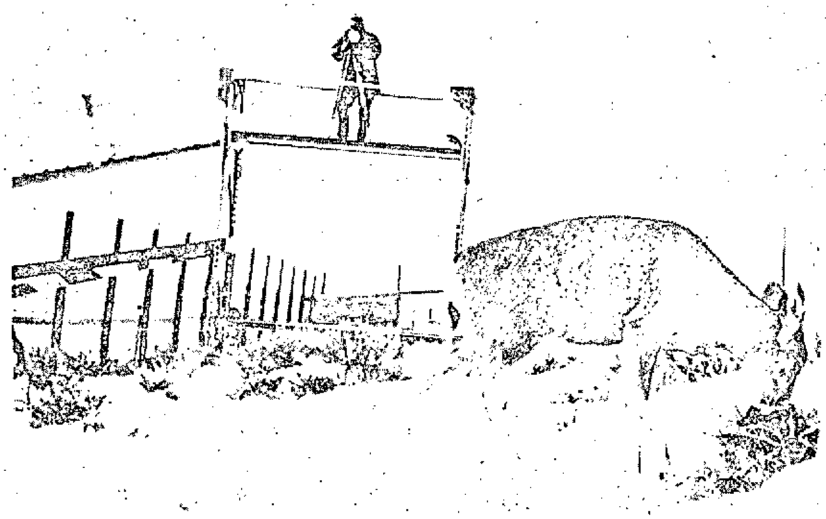

Figure 5. ERT measurements of deer and other objects typical of winter ranges were made from a specially constructed platform extending into the exclosure.

The radiometer, anemometer, and pyranometer data were recorded on FM analog tape. Air temperatures, psychrometer bulb temperature, cloud cover estimates, and time were recorded by hand.

Stepwise, multiple linear regression was used to determine the interactions between the environmental variables and the ERT of deer, sagebrush, and snow. The ERT was the dependent variable; the environmental factors were the independent variables. Also, regression was used to estimate the thermal contrast between deer and sagebrush and deer and snow.

Results and Conclusions

The regression analyses indicated the following with respect to the surface temperature regime and detectability of mule deer in a cold environment:

1. There was an erratic effect of direct solar radiation during daylight hours under clear skies on the ERT of deer such that detection and recognition of the animals would be highly unpredictable (Figure 6). It should be noted that the ERT of a completely sunlit deer surface always exceeded the ERT of the inanimate surfaces after sunrise, approximately 0800 hours. However, the ERT of the shaded deer surface was highly erratic with respect to the ERT of the inanimate surfaces. The combined sunlit-shaded surfaces would be the results of cloudless daytime thermal scanning and, hence, would lead to nonacceptable discrimination errors.

2. In the absence of direct solar radiation, the ERT of deer and the dry background surfaces measured was closely associated with and always greater than air temperature and diffuse solar radiation (Figure 7).

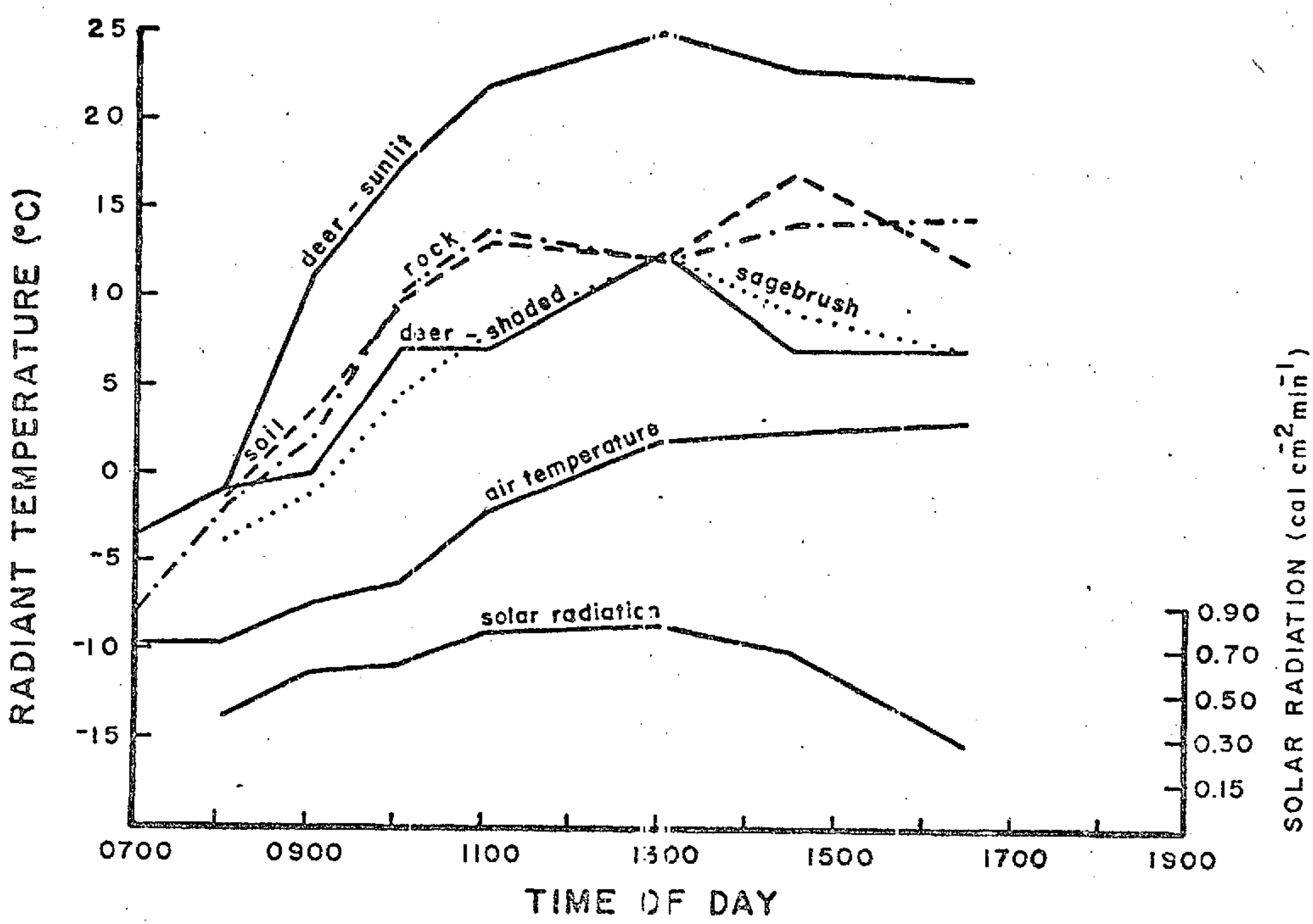

Figure 6. Variation in ERT of deer, rock, soil, and sagebrush on a cloudless day in relation to air temperature and solar radiation. All inanimate surfaces were sunlit.

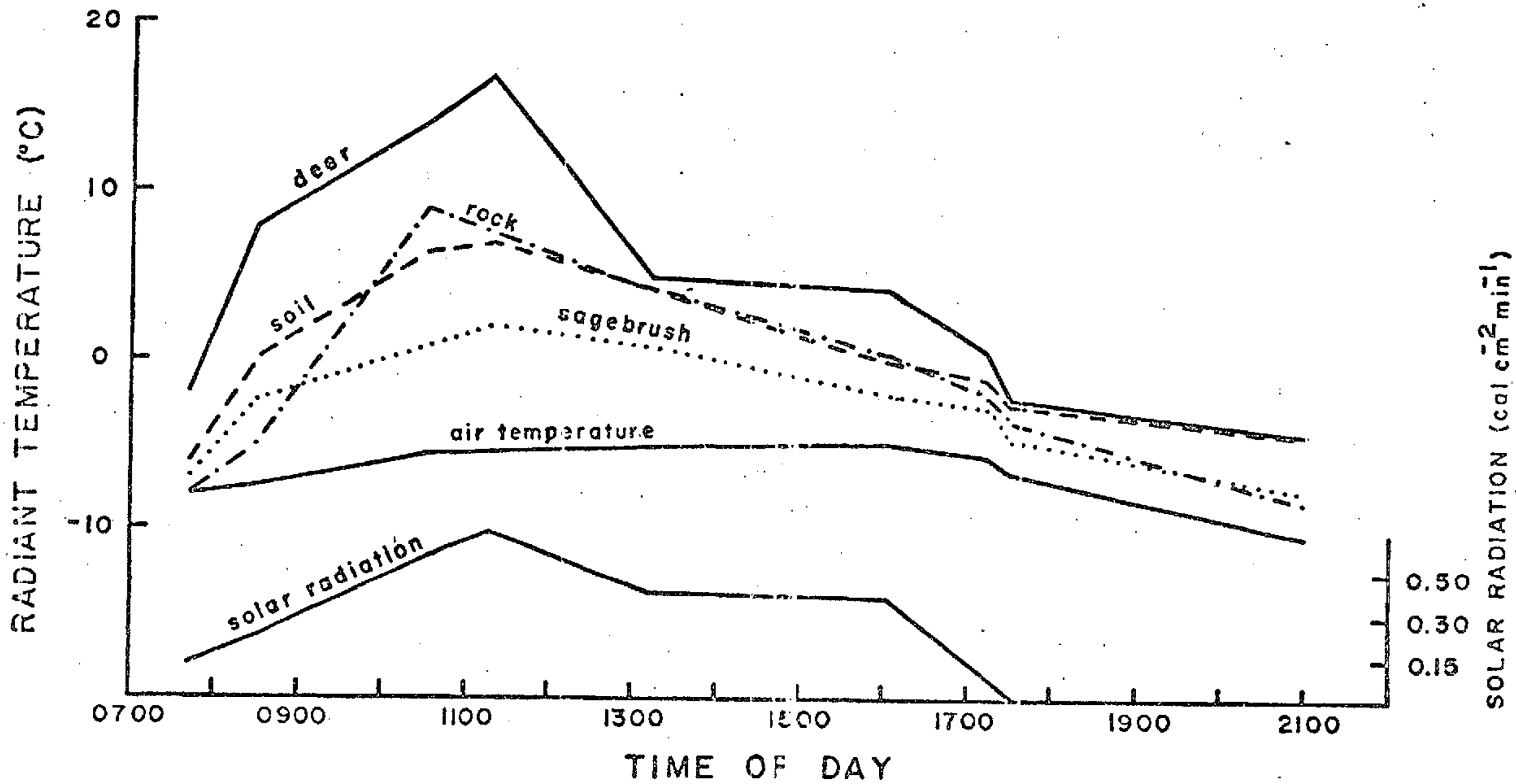

Figure 7. Variation in ERT of deer, rock, soil, and sagebrush on an overcast day in relation to air temperature and solar radiation.

Considering an operational procedure, this set of circumstances would provide possibly the "best" opportunity for deer detection and discrimination provided a mission was planned between 0900 and 1200 hours under conditions similar to those in the Kremmling area. In addition, aircraft navigation problems would be minimized provided the navigational ceiling is satisfactory. However, the logistics of providing equipment and personnel to match the specified conditions would likely prove difficult.

3. On the average, deer ERT exceeded the ERT of the background materials measured in this study, during periods of no direct beam solar illumination, by an amount inversely proportional to air temperature. The thermal contrast between deer and sagebrush or snow, the primary background materials in the study area, would be at least + 2^{o} C with direct solar radiation at zero, a difference sufficient for detection and discrimination with most non-classified, sensitive thermal scanners.

4. The effects of wind could not be realistically assessed because of the measurement technique used. The cup anemometers used essentially measured the laminar flow component, ignoring the turbulence that occurs over uneven surfaces.

There were no environmental conditions during the period of this study under which deer ERT always exceeded the ERT of the background materials except when the background was a complete snow cover. Therefore, there would always be a certain amount of error associated with quantitative detection of wild deer. On this basis, diurnal effects on potential detection should be assessed.

The day may be separated into four periods:

1. Daylight: sunrise to sunset

2. Night: the hours of darkness

3. Post-sunset: the period from sunset to darkness

4. Pre-sunrise: the period from darkness to sunrise.

The daylight period had greatest thermal contrast between deer and background material under the conditions during this study. However, it also is the period when potential discrimination errors are at a maximum on clear days due to either solar heating of background materials or the shading effect.

The night period, after dissipation of residual solar heat, would probably be the "best" time for detection, since the major heat source is the animals. Although thermal contrast between deer and background materials was reduced during this period, there should be sufficient contrast for detection. However, during the dark, safe flying at low altitude is impossible over most winter range areas, considering existing non-classified equipment.

The post-sunset period is free from direct effects of bright sunlight, but the heat-sink in rocks and perhaps bare soil sustains the daytime error potential until well after dark.

The pre-sunrise period probably represents the optimum time for deer detection in a cold environment when visual aircraft navigation is required. The reduction of detection and discrimination errors associated with the night period is maintained until sunrise.

Thermal scanning for mule deer to assist in assessing habitat/animal interactions is not yet operational. More research is needed to quantitatively determine wind effects on detection and discrimination probability of deer, or other large animals, in relation to other environmental factors and background materials. The spectral and spatial requirements of a thermal scan system must also be identified in relation to topographic and aircraft navigational constraints.

Results of this experiment have been presented in a Ph.D. dissertation (Parker 1972b) under the direction of the Principal Investigator, Richard S. Driscoll. A technical journal or Experiment Station paper is planned.

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APPENDIX A

NASA-USDA FORESTRY AND RANGE REMOTE SENSING RESEARCH PROGRAM
"REMOTE SENSING APPLICATIONS IN FORESTRY" SERIES

1966 Annual Reports

STAR* No.	Title
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N66-39386	Lauer, D. T. The feasibility of identifying forest species and delineating major timber types in California by means of high altitude small scale aerial photography. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
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N68-17378	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 22 pages.
N68-17408	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
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**STAR number not available.

STAR No.	Title
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	1971 Annual Reports
N71-32815	Dana, R. W. Calibration of color aerial photography. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 14 pages.
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N72-28324	Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 179 pages.
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N72-28037	Olson, C. E., W. G. Rohde and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 77 pages.
**	Personnel of Forestry Remote Sensing Laboratory. Analysis of remote sensing data for evaluating vegetation resources. School of Forestry and Conservation, University of California. 195 pages.

**STAR number not available.

STAR No.	Title
	1972 Annual Reports
**	Driscoll, R. S. and R. E. Francis. Multistage, multiband and sequential imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 42 pages.
**	Amidon, E. L., D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 23 pages.
**	Poulton, C. E. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Range Management Program, Agricultural Experiment Station, Oregon State University. 48 pages.
**	Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 200 pages.
**	Olson, Jr., C. E. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 26 pages.
**	Personnel of the Forestry Remote Sensing Laboratory. Analysis of remote sensing data for evaluating vegetation resources. School of Forestry and Conservation, University of California, Berkeley. 245 pages.
**	Douglass, R. W., M. P. Meyer and D. W. French. Remote sensing applications to forest vegetation classification and conifer vigor loss due to dwarf mistletoe. College of Forestry, University of Minnesota. 86 pages.

**STAR number not available.

November 15, 1973

LISTING OF NASA THESAURUS TERM CHANGES SINCE SEPTEMBER 1971

The attached listing consists of 850 postable and 322 nonpostable terms added, deleted, or changed in the NASA Thesaurus between September 1971, the publication data of the NASA Thesaurus Alphabetical Update, NASA-SP-7040, and a cutoff date of October 31, 1973. Each nonpostable term is followed by a "USE" designation referring to a postable term. Some postable terms may be followed by explanatory status change designations. An asterisk precedes entries added since the cumulative listing of May 15, 1973.

The NASA Thesaurus contains 18331 terms of which 14837 are postable and 3494 are nonpostable. The next listing (cumulative) of Thesaurus term changes is scheduled for May 1974.

THESAURUS TERM CHANGES SINCE PUBLICATION OF NASA-SP-7040, SEPTEMBER 1971

A-9 AIRCRAFT
A-10 AIRCRAFT
ACLINAL VALLEYS
  USE VALLEYS
* ACOUSTICAL HOLOGRAPHY
ACOUSTO-OPTICS
ACTIVE GLACIERS
  USE GLACIERS
ACTIVE VOLCANOES
  USE VOLCANOES
ADIRONDACK MOUNTAINS (NY)
ADOBE FLATS
  USE FLATS (LANDFORMS)
ADRIATIC SEA
ADVANCED EVA PROTECTION SYSTEMS
  USE AEPS
ADVANCED RECONN ELECTRIC SPACECRAFT
ADVANCING GLACIERS
  USE GLACIERS
ADVANCING SHORELINES
  USE BEACHES
AEPS
AERIAL IMAGERY
  USE AERIAL PHOTOGRAPHY
AERODYNAMIC INTERFERENCE
* AERONAUTICAL SATELLITES
AFRICAN RIFT SYSTEM
AIMP-D
  USE EXPLORER 33 SATELLITE
AIMP-1
  USE EXPLORER 33 SATELLITE
AIMP-2
  USE EXPLORER 35 SATELLITE
AIR LAND INTERACTIONS
AIR SEA INTERACTIONS
  USE AIR WATER INTERACTIONS
AIR WATER INTERACTIONS
* AIRCRAFT MANEUVERS
* AIRCRAFT SURVIVABILITY
. AIRFIELDS
  USE AIRPORTS
ALADIN 2 AIRCRAFT
ALBANIA
ALFALFA
ALGAL BLOOM
  USE ALGAE
ALKALI FLATS
  USE FLATS (LANDFORMS)
ALLUVIAL CONES
  USE ALLUVIUM
ALLUVIAL FANS
  USE FANS (LANDFORMS)
ALLUVIAL FLATS
  USE FLATS (LANDFORMS)
ALLUVIAL PLAINS
  USE FLOOD PLAINS
ALLUVIAL TERRACES
  USE TERRACES (LANDFORMS)
ALLUVIUM
ALPS MOUNTAINS (EUROPE)
ALTOCUMULUS CLOUDS
  USE CUMULUS CLOUDS
AMAZON REGION (SOUTH AMERICA)
AMORPHOUS SEMICONDUCTORS
ANACLINAL STREAMS
  USE STREAMS
ANACLINAL VALLEYS
  USE VALLEYS
ANALYSIS OF VARIANCE
ANDORRA
* ANGINA PECTORIS
ANGIOGRAPHY
ANNULAR DRAINAGE PATTERNS
  USE DRAINAGE PATTERNS
ANOMALOUS TEMPERATURE ZONES
ANS
  USE ASTRONOMICAL NETHERLANDS SATELLITE
ANTICLINAL MOUNTAINS
  USE MOUNTAINS
ANTICLINAL VALLEYS
  USE VALLEYS
ANTICLINES
ANTICLINORIA
  USE ANTICLINES
ANTIREFLECTION COATINGS
ANVIL CLOUDS
APOLLO SOYUZ TEST PROJECT
APOLLO 17 FLIGHT

AQUIFERS
ARCHAEOLOGY
ARCHIPELAGOES
AREA NAVIGATION
ARES (SPACECRAFT)
  USE ADVANCED RECONN ELECTRIC SPACECRAFT
* ARGON-OXYGEN ATMOSPHERES
ARID LANDS
* ARIEL 4 SATELLITE
ARROYOS
* ARTIFICIAL HARBORS
ASH CONES
  USE CONES (VOLCANOES)
ASTP
  USE APOLLO SOYUZ TEST PROJECT
ASTRONOMICAL NETHERLANDS SATELLITE
* ATHEROSCLEROSIS
*   USE ARTERIOSCLEROSIS
ATMOSPHERIC WINDOWS
ATOLL REEFS
  USE CORAL REEFS
ATOLLS
ATOMIC MASS
  USE ATOMIC WEIGHTS
ATOMIC WEIGHTS
AXIAL STREAMS
  USE STREAMS
B-1 AIRCRAFT
BACK BAYS
  USE BAYS (TOPOGRAPHIC FEATURES)
BACKSHORES
  USE BEACHES
BADLANDS
BAHRAIN
BAJADAS
  USE FANS (LANDFORMS)
BALI (INDONESIA)
BALL LIGHTNING
BALTIC SHIELD (EUROPE)
BARBADOS
BARBED TRIBUTARIES
  USE DRAINAGE PATTERNS
BARCHANS
  USE DUNES
BARENTS SEA
BARITO RIVER BASIN (INDONESIA)
BARLEY
BARREN LAND
BARRENS
  USE BARREN LAND
BARRIER BARS
  USE BARS (LANDFORMS)
BARRIER BEACHES
  USE BEACHES
BARRIER FLATS
  USE BARRIERS (LANDFORMS)
BARRIER ISLANDS
  USE ISLANDS
BARRIER LAGOONS
  USE LAGOONS
BARRIER LAKES
  USE LAKES
BARRIER REEFS
  USE REEFS
BARRIERS (LANDFORMS)
BARS (LANDFORMS)
BASIC (PROGRAMMING LANGUAGE)
BASINS
  USE STRUCTURAL BASINS
BATHOLITHS
BAY ICE
BAYHEAD BARS
  USE BARS (LANDFORMS)
BAYHEAD BEACHES
  USE BEACHES
BAYHEAD DELTAS
  USE DELTAS
BAYMOUTH BARS
  USE BARS (LANDFORMS)
BAYOUS
BEAM LEADS
BEAUFORT SEA (NORTH AMERICA)
BEDROCK
BEDS (GEOLOGY)
BELTED PLAINS
  USE PLAINS
BHUTAN
* BIG BANG COSMOLOGY

BIGHORN MOUNTAINS (MT-WY)
BILLOW CLOUDS
  USE CLOUDS (METEOROLOGY)
BIOLOGICAL CLOCKS
  USE RHYTHM (BIOLOGY)
BIOREGENERATIVE LIFE SUPPORT SYSTEMS
  USE CLOSED ECOLOGICAL SYSTEMS
BIPOLAR TRANSISTORS
BIRDFOOT DELTAS
  USE DELTAS
BLACK HILLS (SD-WY)
BLACK HOLES (ASTRONOMY)
BLADDER MECHANICS DELETED
BLADDERS (MECHANICS)
  USE DIAPHRAGMS (MECHANICS)
BLIGHT
* BLOCK DIAGRAMS
BLOCK ISLAND SOUND (RI)
BLOOD VOLUME
BODY-WING CONFIGURATIONS
BOGS
  USE MARSHLANDS
BOLL WEEVILS
BOLLWORMS
BOTSWANA
* BOUNDARY LAYER EQUATIONS
BRAIDED STREAMS
  USE STREAMS
BREAKWATERS
BRIDGES (LANDFORMS)
BRITISH HONDURAS
BROKEN CLOUDS
  USE CLOUDS (METEOROLOGY)
BRUNEI
BRUSH (BOTANY)
BSI
BURUNDI
BUTTES
C-1A AIRCRAFT
CAMEROON
CANNONBALL 2 SATELLITE
CANYONS
CAP CLOUDS
CAPES (LANDFORMS)
CARBON FIBER REINFORCED PLASTICS
* CARBON-CARBON COMPOSITES
CARIBOUS
CASCADE RANGE (CA-OR-WA)
CATCHMENT AREAS
  USE WATERSHEDS
CAYS
  USE KEYS (ISLANDS)
CDC 6400 COMPUTER
CENSUS
CENTRAL AFRICAN REPUBLIC
CENTRAL ATLANTIC REGION (US)
CENTRAL EUROPE
CENTRAL PIEDMONT (US)
CFRP
  USE CARBON FIBER REINFORCED PLASTICS
CHAD
CHANNEL MULTIPLIERS
CHANNELTRONS
  USE CHANNEL MULTIPLIERS
CHAOTIC CLOUD PATTERNS
  USE CLOUDS (METEOROLOGY)
CHAPARRAL
CHENA RIVER BASIN (AK)
CHESAPEAKE BAY (US)
CHIAPAS (MEXICO)
CHINA (COMMUNIST) MAINLAND
  USE CHINESE PEOPLES REPUBLIC
CINDER CONES
  USE CONES (VOLCANOES)
CIRQUES (LANDFORMS)
CIRROCUMULUS CLOUDS
CIRROSTRATUS CLOUDS
CIRRUS SHIELDS
CITRUS TREES
CLOSED BASINS
  USE STRUCTURAL BASINS
CLOSED FAULTS
  USE GEOLOGICAL FAULTS
CLOSED FOLDS
  USE FOLDS (GEOLOGY)
CLOUD STREETS
  USE CLOUDS (METEOROLOGY)
COACHELLA VALLEY (CA)
COASTAL CURRENTS
COASTAL DUNES
  USE DUNES
COASTAL MARSHES
  USE MARSHLANDS
COASTAL PLAINS
COASTAL WATER
COFFEE
COLD FRONTS
* COLLISIONAL PLASMAS
COLORADO PLATEAU (US)
COLS
  USE GAPS (GEOLOGY)
COMET HEADS
COMET NUCLEI
COMET TAILS
COMMUNICATIONS TECHNOLOGY SATELLITE
COMPUTER SYSTEMS DESIGN
COMPUTERIZED CONTROL
  USE NUMERICAL CONTROL
CONES (VOLCANOES)
CONGO (BRAZZAVILLE)
CONGO (KINSHASA)
  USE ZAIRE
CONIFERS
CONSEQUENT LAKES
  USE LAKES
CONSEQUENT STREAMS
  USE STREAMS
CONSEQUENT VALLEYS
  USE VALLEYS
CONTACTS (GEOLOGY)
* CONTINUOUS SPECTRA
CONTINUOUS WAVE LASERS
CONTROL STICKS
CONVECTION CLOUDS
COOK INLET (AK)
* COPERNICUS SPACECRAFT
*   USE OAO 3
COPSES
CORAL HEADS
  USE CORAL REEFS
CORN
CORROSION TEST LOOPS
COS-B SATELLITE
COSMOS 381 SATELLITE
COTTON
COULEES
  USE CANYONS
CRATONS
CROP IDENTIFICATION
CROPLANDS
  USE FARMLANDS
CROSS FAULTS
  USE GEOLOGICAL FAULTS
CROSSBEDDING (GEOLOGY)
CRUSTAL FRACTURES
CUBA
CUESTAS
  USE RIDGES
CULTURAL RESOURCES
CURIUM COMPOUNDS
CURRENT CONVERTERS (AC TO DC)
CURRENTS (OCEANOGRAPHY)
  USE WATER CURRENTS
CUSPS (LANDFORMS)
* CYCLOGENESIS
CYPRUS
* D-2 SATELLITES
* D-2B SATELLITE
*   USE D-2 SATELLITES
DAHOMEY
DATA BASES
DATA COLLECTION PLATFORMS
DATA CONVERSION ROUTINES
DDP COMPUTERS
DDP 516 COMPUTER
DECIDUOUS TREES
* DEEPWATER TERMINALS
DEFOLIATION
DEFORESTATION
* DELAWARE RIVER BASIN (US)
* DELPHI METHOD (FORECASTING)
DELTAIC COASTAL PLAINS
  USE COASTAL PLAINS
DELTAS
DENDRITIC DRAINAGE
  USE DRAINAGE PATTERNS

* DENSE PLASMAS
DEPRESSIONS (TOPOGRAPHY)
USE STRUCTURAL BASINS
DESERTLINE
DIADEME SATELLITES
REPLACES DIADEME SATELLITE
DIASTOLIC PRESSURE
DIELECTRIC CONSTANT
USE PERMITTIVITY
DIFFRACTION LIMITED CAMERAS
DIKES
USE ROCK INTRUSIONS
DISEASED VEGETATION
USE BLIGHT
* DISTRIBUTED PARAMETER SYSTEMS
DIVIDES (LANDFORMS)
DOMINICA
DOMINICAN REPUBLIC
DORMANT VEGETATION
USE VEGETATION
DRAINAGE PATTERNS
DROP TRANSFER
DROUGHT
DROUGHT CONDITIONS
USE DROUGHT
DRUMLINS
USE GLACIAL DRIFT
DUNES
* DYE LASERS
* DYSPROSIUM COMPOUNDS
EAI 8400 COMPUTER
EAI 8900 COMPUTER
EARTH RESOURCES EXPERIMENT PACKAGE
USE EREP
* EARTH RESOURCES INFORMATION SYSTEM
EARTH RESOURCES OBSERVATION SATELLITES
USE EROS (SATELLITES)
* EARTH RESOURCES SURVEY PROGRAM
* EARTH RESOURCES TECHNOLOGY SATELLITE A
* USE EARTH RESOURCES TECHNOLOGY SATELLITE 1
EARTH RESOURCES TECHNOLOGY SATELLITE B
EARTH RESOURCES TECHNOLOGY SATELLITE C
EARTH RESOURCES TECHNOLOGY SATELLITE D
EARTH RESOURCES TECHNOLOGY SATELLITE E
EARTH RESOURCES TECHNOLOGY SATELLITE F
* EARTH RESOURCES TECHNOLOGY SATELLITE 1
EARTH TIDES
EARTHQUAKE DAMAGE
EAST GERMANY
EBF
USE EXTERNALLY BLOWN FLAPS
ECHELON FAULTS
USE GEOLOGICAL FAULTS
ECHOCARDIOGRAPHY
* ECONOMIC DEVELOPMENT
ECOSYSTEMS
EFFECTIVE PERCEIVED NOISE LEVELS
EL SALVADOR
ELECTRIC POWER SUPPLIES
ELECTROMAGNETIC NOISE MEASUREMENT
* ELECTROMAGNETIC SURFACE WAVES
ELLIPTICAL GALAXIES
EMR 6050 COMPUTER
END MORAINES
USE GLACIAL DRIFT
ENERGY TRANSFER
SCOPE NOTE IS DELETED

energy policy – E reports only

ENGLAND
ENGLISH CHANNEL
ENTRENCHED STREAMS
USE STREAMS
ENVIRONMENT EFFECTS
ENVIRONMENT MANAGEMENT
ENVIRONMENT PROTECTION
ENVIRONMENTAL QUALITY
ENVIRONMENTAL SURVEYS
EOLE SATELLITES
EOS-A
USE EARTH RESOURCES TECHNOLOGY SATELLITE E
EOS-B
USE EARTH RESOURCES TECHNOLOGY SATELLITE F
EPNL
USE EFFECTIVE PERCEIVED NOISE LEVELS
EREP
EROS (SATELLITES)
* ERTS-A
* USE EARTH RESOURCES TECHNOLOGY SATELLITE 1
ERTS-B
USE EARTH RESOURCES TECHNOLOGY SATELLITE B
ERTS-C
USE EARTH RESOURCES TECHNOLOGY SATELLITE C
ERTS-D
USE EARTH RESOURCES TECHNOLOGY SATELLITE D
ERTS-E
USE EARTH RESOURCES TECHNOLOGY SATELLITE E
ERTS-F
USE EARTH RESOURCES TECHNOLOGY SATELLITE F
ESCARPMENTS
ESKERS
USE GLACIAL DRIFT
ESRO 4 SATELLITE
ESTONIA
ETHIOPIA
EUROPA
EUTROPHICATION
EVAPOTRANSPIRATION
EXPERIMENTAL STOL TRANSPORT RSCH AIRPLANE
USE QUESTOL
* EXPLORER 47 SATELLITE
* EXPLORER 49 SATELLITE
EXTERNALLY BLOWN FLAPS
EXTRAGALACTIC MEDIA
USE INTERGALACTIC MEDIA
EXTRAGALACTIC RADIO SOURCES
EXTRASOLAR PLANETS
EXTRATERRESTRIAL ROVING VEHICLES
USE ROVING VEHICLES
EXTREMELY LOW FREQUENCIES
* F-114 AIRCRAFT
* DELETED TERM
FALLOW FIELDS
USE FARMLANDS
FANS (LANDFORMS)
FARMLANDS
* FAST FOURIER TRANSFORMATIONS
FEASIBILITY ANALYSIS
FEDERAL REPUBLIC OF GERMANY
USE GERMANY
FERRIC IONS
CHANGED FROM FERRIC ION
FERRITIC STAINLESS STEELS
FILAMENT WOUND CONSTRUCTION
USE FILAMENT WINDING
* FFT
* USE FAST FOURIER TRANSFORMATIONS
* FIBER ORIENTATION
* FIBONACCI NUMBERS
FILE MAINTENANCE (COMPUTERS)
* FILTER WHEEL INFRARED SPECTROMETERS
FINGER LAKES
USE LAKES
FIORDS
FIRE DAMAGE
FIREBREAKS
FIXED POINT ARITHMETIC
FLATS (LANDFORMS)
FLOOD DAMAGE
FLOOD PLAINS
FLUIDIC CIRCUITS
FOLDS (GEOLOGY)
FORENSIC SCIENCES
USE LAW (JURISPRUDENCE)
FOREST FIRE DAMAGE
USE FIRE DAMAGE
FOREST FIRES
FOREST MANAGEMENT
FREEZE DRYING
FRENCH SATELLITES
REPLACES FRENCH SATELLITE
FREON
REACTIVATED IN LIEU OF FREON (TRADEMARK)
* FRICTION WELDING
FRONTAL WAVES
FROST DAMAGE
FROZEN LAKES
USE LAKES
FROZEN SOILS
USE PERMAFROST
FUNCTIONALS
GABON
GADOLINIUM ISOTOPES
GALACTIC CLUSTERS
GALACTIC NUCLEI
GALACTIC ROTATION
GALACTIC STRUCTURE
GALLIUM OXIDES

GAMBIA
GAPS (GEOLOGY)
GARP
  USE GLOBAL ATMOSPHERIC RESEARCH PROGRAM
GASDYNAMIC LASERS
GASP
  USE GLOBAL AIR SAMPLING PROGRAM
* GE COMPUTERS
* GE 235 COMPUTER
GE 625 COMPUTER
GE 635 COMPUTER
* GENERAL ELECTRIC COMPUTERS
* USE GE COMPUTERS
GEOFRACTURES
  USE GEOLOGICAL FAULTS
* GEOLE SATELLITES
GEOLOGICAL SURVEYS
GEOS SATELLITES (ESRO)
GEOSTATIONARY OPERATIONAL ENVIRON SATS
  USE GOE SATELLITES
GEOSYNCLINES
* GEOTHERMAL ENERGY CONVERSION
* GEOTHERMAL RESOURCES
GHANA
GLACIAL DRIFT
GLACIOFLUVIAL DEPOSITS
  USE GLACIAL DRIFT
* GLASS FIBER REINFORCED PLASTICS
GLOBAL AIR SAMPLING PROGRAM
GLOBAL ATMOSPHERIC RESEARCH PROGRAM
GLOBULAR CLUSTERS
GOBI DESERT
GOE SATELLITES
GORGES
  USE CANYONS
GRABENS
  USE GEOLOGICAL FAULTS
GRASSLANDS
GRAVEL DEPOSITS
  USE GRAVELS
GRAZING
GRAZING LANDS
  USE GRASSLANDS
* GREAT BASIN (US)
GREAT LAKES (NORTH AMERICA)
GREAT PLAINS CORRIDOR (NORTH AMERICA)
GRIGG-SKJELLERUP COMET
GUADELOUPE
GUATEMALA
GULF OF ALASKA
GULF OF CALIFORNIA (MEXICO)
GULF OF MEXICO
* GUM NEBULA
* GUNN DIODES
GUYANA
HABITATS
HAITI
HARBORS
HARD LANDING
HARDWOOD FORESTS
  USE FORESTS
HARRIER HELICOPTERS
HAWKEYE SATELLITES
HAY
HAZE DETECTION
HCN LASERS
HEART VALVES
* HEAT ACCLIMATIZATION
* CHANGED FROM NONPOSTABLE
HELIOS A
HELIOS B
HELIOS PROJECT
HELIOS SATELLITES
* HELIUM-OXYGEN ATMOSPHERES
HEWLETT-PACKARD COMPUTERS
HIGH DISPERSION SPECTROGRAPHS
HIGH SPEED TRANSPORTATION
  USE RAPID TRANSIT SYSTEMS
HIGHLY ECCENTRIC ORBIT SATELLITES
  USE HEOS SATELLITES
* HIS BUNDLE
HOGBACKS
  USE RIDGES
* HOLOGRAPHIC INTERFEROMETRY
HONDURAS
HONEYWELL COMPUTERS
HONG KONG
HOURGLASS VALLEYS
  USE VALLEYS
HUBBLE CONSTANT
  USE HUBBLE DIAGRAM
HUBBLE DIAGRAM
HUMAN RESOURCES
HYDROCYANIC ACID
HYDROELECTRIC POWER STATIONS
HYDROGEN CHLORIDES
* HYDROGEN CYANIDES
* USE HYDROCYANIC ACID
* HYDROGEN EMBRITTLEMENT
HYDROPOWER STATIONS
  USE HYDROELECTRIC POWER STATIONS
* HYPERBOLIC DIFFERENTIAL EQUATIONS
HYPERSONIC WIND TUNNELS
  CHANGED TO POSTABLE
  SCOPE NOTE (MACH 5 TO 10)
HYPERVELOCITY WIND TUNNELS
  SCOPE NOTE CHANGED TO (ABOVE MACH 10)
HYPSOGRAPHY
* IBM 1050 COMPUTER
* DELETED
* IBM 2701 COMPUTER
* DELETED
ICE FLOES
ICE JAMS
  USE ICE
ICE PACKS
  USE SEA ICE
IFNI
ILLIAC 3 COMPUTER
IMBLMS
* IMP-H
* USE EXPLORER 47 SATELLITE
IMP-1
  USE EXPLORER 18 SATELLITE
IMP-2
  USE EXPLORER 21 SATELLITE
IMP-3
  USE EXPLORER 28 SATELLITE
IMP-4
  USE EXPLORER 34 SATELLITE
IMP-5
  USE EXPLORER 41 SATELLITE
IMP-6
  USE EXPLORER 43 SATELLITE
IMPATT DIODES
  USE AVALANCHE DIODES
IMPERIAL VALLEY (CA)
IMPROVED TIROS OPERATIONAL SATELLITES
  CHANGE FROM NONPOSTABLE
INCOMPRESSIBILE BOUNDARY LAYER
INDONESIA
* INDUCTION MOTORS
INDUSTRIAL AREAS
INFESTATION
INFRARED INTERFEROMETERS
INLETS (TOPOGRAPHY)
INLIERS (LANDFORMS)
INSECT DAMAGE
  USE INFESTATION
INSEQUENT STREAMS
  USE STREAMS
INSHORE ZONES
  USE BEACHES
INTEG MED AND BEHAVIORAL LAB MEASUR SYSTEM
  USE IMBLMS
INTERCOSMOS SATELLITES
INTERFACES
  SCOPE NOTE DELETED
INTERLACING DRAINAGE
  USE DRAINAGE PATTERNS
INTERMONTANE FLOORS
  USE VALLEYS
INTERNATIONAL FIELD YEAR FOR GREAT LAKES
INTERNATIONAL ULTRAVIOLET EXPLORER
  USE IUE
INTERSTELLAR REDDENING
  USE INTERSTELLAR EXTINCTION
INTRUSIONS
  USE ROCK INTRUSIONS
INVERTED CONVERTERS (DC TO AC)
IO
ION ACOUSTIC WAVES
* ION IMPLANTATION
IRAQ
ISLAND ARCS
ISTHMUSES

ITOS 2
ITOS 3
ITOS 4
IUE
IVORY COAST
I2S CAMERAS
J-58 ENGINE
JAMAICA
JETTIES
  USE BREAKWATERS
JIMSPHERE BALLOONS
KALIHARI BASIN (AFRICA)
KALMAN FILTERS
KAME
  USE GLACIAL DRIFT
KARST
KELP
  USE SEAWEEDS
* KELVIN-HELMHOLTZ INSTABILITY
KENYA
KETTLES (GEOLOGY)
KEYS (ISLANDS)
KLIPPEN
  USE OUTLIERS (LANDFORMS)
KOREA
KOREA
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  CHANGED TO METALLIC MATERIALS TERM
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* WINDPOWERED GENERATORS
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WRANGELL MOUNTAINS (AK)
X MESONS
X RAY SOURCES
X RAY SPECTRA
YAG LASERS
YELLOWSTONE NATIONAL PARK (ID-MT-WY)
ZAIRE
ZAMBIA

February 8, 1974

NASA THESAURUS TERMS ADDED OR CHANGED DURING JANUARY 1974

AUGER SPECTROSCOPY

BARIUM ION CLOUDS

CONDITIONED REFLEXES

CORNER FLOW

DATA COMPRESSION

DATA COMPRESSORS DELETED

ENERGY POLICY

FLAME RETARDANTS

HELOS (SATELLITE)

HF LASERS

HIGH ECCENTRIC LUNAR OCCULTATION SATELLITE

USE HELOS (SATELLITE)

KOHOUTEK COMET

LAGEOS (SATELLITE)

LASER DOPPLER VELOCIMETERS

LASER GEODYNAMIC SATELLITE

USE LAGEOS (SATELLITE)

MARITIME SATELLITES

MOTION PERCEPTION CHANGED TO POSTABLE

OPERATIONAL AMPLIFIERS

OUTLET FLOW

OXIDE FILMS

PARTICLE TRACKS CHANGED TO POSTABLE

REYNOLDS STRESS

SACCADIC EYE MOVEMENTS

SPECIMEN GEOMETRY — The diameter, length, size or overall geometry of a test specimen used in tensile, fatigue, load, or other tests

SPECKLE PATTERNS — A particular type of irregular pattern resulting from the intermodulation of laser light scattered on a rough surface

STOKES LAW OF RADIATION

YC-14 AIRCRAFT

YF-16 AIRCRAFT

NASA THESAURUS TERMS ADDED OR CHANGED DURING FEBRUARY 1974

ANIK A

ANIK B

ATS   Replaces APPLICATIONS TECHNOLOGY SATELLITES

AUTOMOBILE FUELS

CLEAN ENERGY

COAL GASIFICATION

COAL LIQUEFACTION

COAL UTILIZATION

COMMERCIAL ENERGY

DIESEL FUELS

ENERGY COMSUMPTION

ENERGY TECHNOLOGY

FISSILE FUELS

FOSSIL FUELS

GAS COOLED FAST REACTORS

GASIFICATION

HIGH TEMPERATURE GAS COOLED REACTORS

HTGR

  USE HIGH TEMPERATURE GAS COOLED REACTORS

HYDROGEN-BASED ENERGY

INDUSTRIAL ENERGY

KEROGEN

LAKE ERIE
LAKE HURON
LAKE MICHIGAN

LAKE ONTARIO

LAKE SUPERIOR

LIGHT WATER BREEDER REACTORS

LIQUEFIED NATURAL GAS

LIQUID METAL FAST BREEDER REACTORS

LMFBR

USE LIQUID METAL FAST BREEDER REACTORS

LNG

USE LIQUEFIED NATURAL GAS

OFFSHORE ENERGY SOURCES

OIL RECOVERY

ORGANIC WASTES (FUEL CONVERSION)

RECYCLING

CHANGED TO POSTABLE

SHALE OIL

SOLAR ENERGY CONVERSION

SUPERCONDUCTING POWER TRANSMISSION

SYNTHANE

SYNTHETIC FUELS

SYNTHETIC METHANE

USE SYNTHANE

TAR SANDS

TELESAT CANADA A

USE ANIK A

TELESAT CANADA B

USE ANIK B

TRANSPORTATION ENERGY

WASTE ENERGY UTILIZATION